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Assessment procedure of the trafficability of inland waterways

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Abstract

A sophisticated procedure on the basis of a geographic information system (GIS) was developed to contribute to the assessment and evaluation of the trafficability of inland waterways. Besides the given geometry of a free flowing river, the results of hydrodynamic numerical river basin models (HN-model), the ship dynamic parameters of an inland vessel and additional information from the Inland Electronic Navigational Chart (Inland ENC) are taken into consideration in the assessment procedure *RiNA* (*River Navigation Assessment*). After the transmission of various, complex initial data into a mutual system, firstly the so-called single potential areas are generated from the nautically relevant parameters (e.g. flow depths, flow velocities, draught, safety distance, fairway, berths, regulation of the traffic). Then those single potential areas are transferred to total potential areas by suitable combination. The total potential areas represent a surface distribution of the navigable areas of waterways and show the trafficability. These total potential areas are prepared regarding different discharge scenarios, types of ships, changes in the draught, direction (up-/downstream) and then validated by recorded passages of vessels. With this procedure an assessment and evaluation of waterways according to nautical criteria (among others flow velocity, draught, driving rules) can be performed and critical points (e.g. bottlenecks) can be shown, which in future leads to an optimized use of the waterways. On the basis of different case studies of the river Rhine in Germany the application of the assessment procedure were shown.

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Keywords: Geographic Information System (GIS); Hydrodynamic-numerical model; Inland Electronic Navigational Chart (Inland ENC); ship dynamic parameters; inland waterways; River Navigation Assessment (RiNA);

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1. Introduction

Hydrodynamic-numerical (HN-) models for simulating flows in bodies of water and methods for modelling ship manoeuvring have for some time now played an integral role in the field of hydraulic engineering. In engineering practice high-resolution HN-models for the temporal and spatial simulation of flows and, if required, sediment transport, are widely applied in the assessment and evaluation of extension and maintenance measures of the inland waterways. Over the past decades, the modelling of ship manoeuvring which is used, for example, to determine the required swept area width has been further developed, from simple geometric estimations in canals to increasingly sophisticated and complex methods taking account of riverine geometry, flow characteristics in bodies of flowing water as well as the dynamics of a ship's movements.

Variable parameters such as discharge and flow characteristics, climate change, evolution of traffic, increasing vessel dimensions, etc. must be taken into account and appropriate maintenance and extension planning be provided to ensure or enhance the long-term performance of waterways. A recurrent issue in this respect is that of determining whether the trafficability of inland waterways is ensured under continuously changing boundary conditions and requirements. This is a permanent task which must be supported by the proper tools and simulation methods and procedures.

It involves, on the one hand, increasing the economic efficiency of inland navigation by using ever larger vessel dimensions (more capacity for the transport of goods), improved equipment on board ships (more powerful manoeuvring units) and the provision of inland navigation information services (e.g. the electronic information system about German inland waterways ELWIS). The aim of river information services is to contribute to a safe and efficient transport process and thus to intensive utilisation of the capacity of inland waterways [3]. On the other hand, the economic operation of waterways depends on natural determining factors such as hydrologic and, consequently, discharge conditions. A major requirement regarding high-capacity inland waterways is a fairway which is adapted to approved vessel dimensions, i.e. ensuring sufficient fairway width and depth to enable safe, easy and economically efficient operation throughout the year. Appropriate river engineering measures increase the usable flow depth, thus improving the trafficability of a waterway during low and mean water periods in particular. On the River Rhine for example, Germany's major waterway, such measures include the construction and maintenance of regulating structures (e.g. transversal and longitudinal groynes). Despite the variability of boundary conditions a sufficient width and depth of the fairway should be maintained over the largest possible reach or even the entire network of navigable waterways.

There is no universal method for assessing and evaluating the navigability of inland waterways and for visualising the surface distribution of the navigable areas and showing the trafficability. The approach used to determine a waterway's trafficability depends on the underlying question and objective. In many cases, very different methods and a variety of input data are used. Depending on the requirements relating to waterways, different procedures have been developed over time to deal with problems and issues in an efficient way. This may involve field investigations, laboratory measurements, the modelling of ship manoeuvring and application of hydrodynamic-numerical methods or the use of on-board supporting systems such as the inland navigation information services.

2. Development of an assessment procedure

This study aims at developing a procedure (*RiNA - River Navigation Assessment*) for assessing and evaluating the trafficability of inland waterways and visualising navigable areas. Different elements from several disciplines will be used to characterise trafficability (see Fig. 1). These are the geometric properties of the river and the navigation channel, the vessel characteristics and the flow characteristics and their interactions. This approach also considers the inland navigation information services supporting navigation as well as navigation rules. The nautically relevant information from the different departments will be used, processed and augmented across disciplines. The information can then be appropriately combined for evaluation purposes.

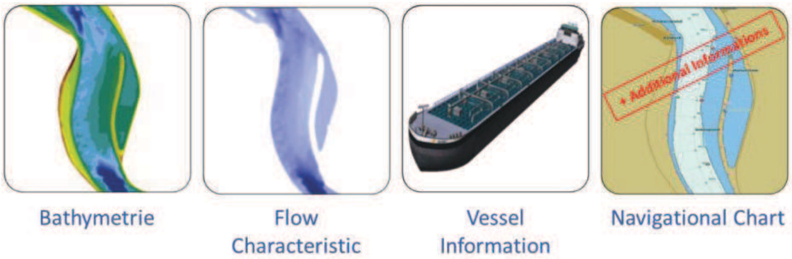

Fig. 1. Different elements of the *RiNA* (*River Navigation Assessment*) procedure for assessing and evaluating the trafficability of inland waterways and visualising the navigable area

2.1. Description

The assessment procedure leans mainly on the input data from the different disciplines (information from the Inland ENC and additional data, if necessary, flow data derived from HN-models and the characteristics of an inland vessel and/or fairway requirements). The first step is to combine the (vector and raster) data from different disciplines in a single system (e.g. geographic information system GIS). The present study uses ArcGIS, which is widely applied around the world to transfer, prepare and process the various interdisciplinary data in a single system, where necessary by transformation of coordinates. Where no raster information is available, the data must be transformed into raster datasets (e.g. by triangulation, conversion) to allow the appropriate calculation operations (standardisation, reclassification, weighting) in the area. The different single potential areas can be calculated after the potential values have been allocated (see sub-section 2.2). The total potential area is developed by using the appropriate combination of the single potential areas (see sub-section 2.3), which allows the trafficability of inland waterways to be assessed and evaluated and the navigable areas to be visualised. The procedure is validated based on recorded passages downstream and upstream which were undertaken by different inland navigation vessels on characteristic reaches of the River Rhine in Germany under various discharge conditions. Preparing, processing and combining the various interdisciplinary input data as well as performing the calculation process and analysing the results involves a great deal of work and is only possible with software engineering support (see sub-section 2.4).

2.2. Development of single potential

Appropriate criteria must be defined for the development of a potential depending on the issue which is studied, the available data and the size of the study area. For instance, the objects and parameters (e.g. flow depth and flow velocity) for the development of the single potential have to be defined. Additionally, safety margins, velocity and draught must be specified and the appropriate method for the development of the potential (e.g. constant, distance-based or multi-stage procedure) and the cell resolution determined.

2.2.1. Information from the Inland ENC

Nautically relevant information is separated from the vector-based Inland ENC. Potential values are then allocated to the information before it is converted into raster information. For this purpose the S-57 data format of the Inland ENC is first interpreted and then transformed into so-called point, lines or surface shapefiles. A safety clearance (e.g. around a bridge pier, berth areas, etc.) can be defined for each object. The value of the potential is specified in the table of attributes. For the development of the potential relating to the Inland ENC objects a distinction is made between two procedures: constant or distance-based allocation of potential value. Fig. 2 shows the example of a potential development for a fairway buoy against the background of digital orthophotos. The buoy is visible on the left-hand side. The picture in the middle shows the potential of the fairway buoy with constant potential value allocation with a chosen safety clearance of 10 m, while the image on the right hand side represents the distance-based allocation procedure where the potential value decreases with increasing distance from the buoy. By using the Euclid distance approach it is possible to determine the distance from one raster cell to the nearest source (point, lines or surface shapefile). The procedures can be applied to any objects from the Inland ENC. The potential development method comprises several calculation and intermediary steps to allow the comparison and/or mathematical combination of the single potential areas obtained.

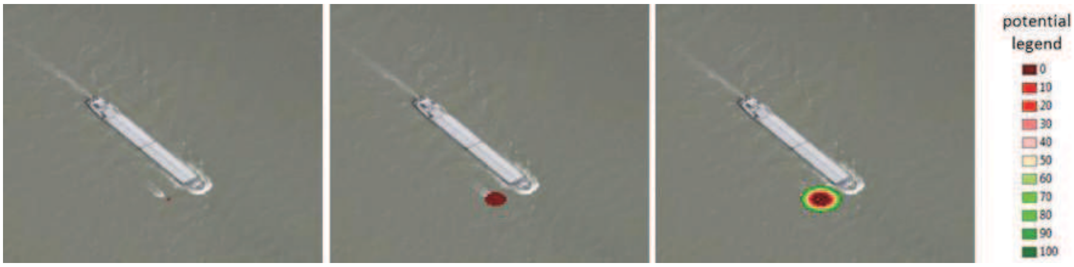

Fig. 2. Potential development for a fairway buoy: position obtained from Inland ENC (left); safety distance 10 m and potential value allocation 0 (central); decreasing potential value with increasing distance to buoy (right)

For an all-encompassing assessment and evaluation of trafficability, depending on the issue and study area, it is necessary to develop further single potential areas based on additional information, for example navigation rules. These include fairway separation, rules for passage under bridges, prohibition of meeting/overtaking manoeuvres, provisions for meeting manoeuvres, restrictions to navigation in the event of floods. In Germany, navigation restrictions applicable during floods between flood marks I and II in a specific gauge section are governed for the river Rhine by the Rhine Police Regulations [2]. Vessels must try to keep to the centre of the river when sailing downstream and to the central third of the river when sailing upstream.

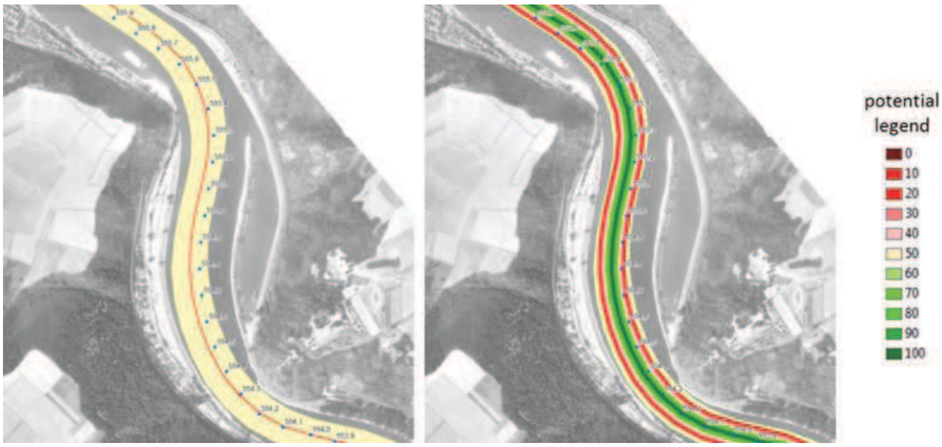

Fig. 3. Development of potential using nautically relevant additional information (here: downstream sailing vessel keeping as close as possible to the centre, with a water level in the relevant gauge section between flood marks I and II)

Fig. 3 provides an example of the development of the potential in the case of a downstream moving vessel which is required to keep to the centre of the stream when the water level in the relevant gauge section is between flood mark I and II. For this purpose the centreline (red line) of the fairway (yellow area) was determined in a first step because this line does not necessarily coincide with the centreline of the water body (blue dots) derived from the Inland ENC. The distance analysis is carried out on both sides based on the fairway centreline determined in this way and using a distance of 50 m in this example, to generate a distance-based development of potential (see Fig. 3).

2.2.2. Flow characteristics from the hydrodynamic-numerical model

The relevant flow characteristics required to assess and evaluate the trafficability of inland waterways are the flow depths on the one hand and the flow velocities on the other. These are obtained from a multi-dimensional flow model. The calculated flow results must be provided in a raster data format before they can be used for potential development. Each raster cell must first be normalised with the respective parameters and then reclassified to match the potential legend. When developing the potential for the flow depths an upper release value for the depth (the sum of draught, squat, underkeel clearance and safety margins or reference values as a percentage of draught) must be specified for normalisation. This value represents the best possible preconditions for trafficability. Moreover, a minimum depth must be defined which represents the threshold for trafficability. The minimum depth is the draught (plus safety margins). Fig. 4 shows the raster and the potential development for the flow depths. When developing the potential for the flow velocities, a distinction must be made between downstream and upstream navigation and a velocity limit must be specified. As a rule this entails an inverse reclassification as shown in Fig. 5 because the upstream moving vessel looks for the part of the navigation channel which has the lowest flow velocities in order to sail faster and vice versa. Fig. 5 (right) shows that, under these discharge conditions, there are areas which cannot be navigated by vessels sailing upstream because the flow velocities exceed the defined velocity limit.

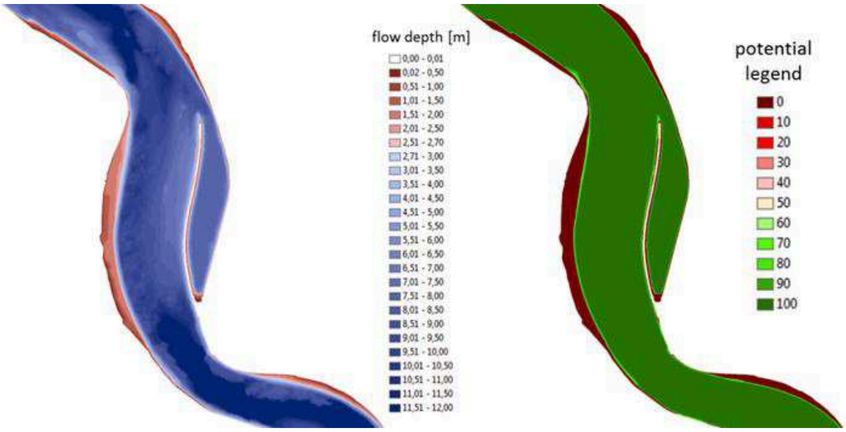

Fig. 4. Flow depth raster from the HN-model (left); development of potential for flow depth (right) with upper release value of 5 m for the depth (normalisation) and a minimum depth of 3 m (reclassification)

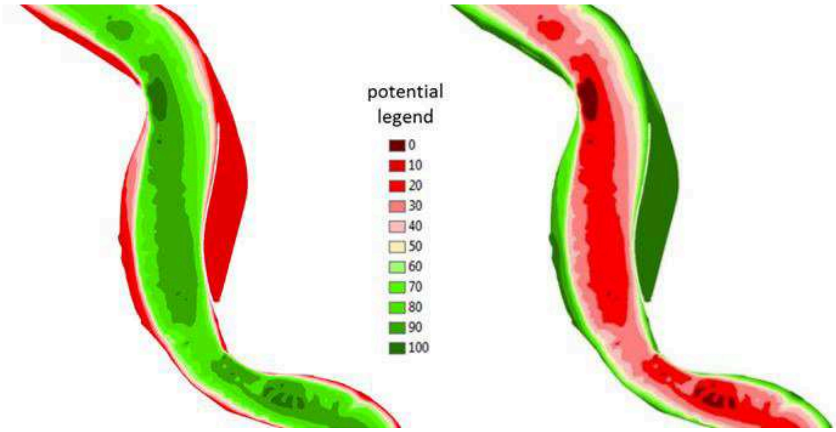

Fig. 5. Comparison of single potential development for flow velocity for downstream (left) and upstream (right) navigation

2.3. Total potential development and validation

The single potential areas developed on the bases of the numerous input data are aggregated into total potential areas in the next step using weighting factors (see Fig. 6 and Fig. 7). The total potential is valid for a specific discharge, taking account of the defined nautical characteristics of the vessel and/or the fairway and the distinction between downstream and upstream navigation. For the development of the total potential areas account must be taken of the fact that a non-navigable single potential will lead to a non-navigable total potential when the weighted parts are summed up. Validation of the procedure is based on recorded passages (downstream and upstream) of different types of inland navigation vessels (inland tank barge, TMS; large motor vessel; GMS, extra-long large motor vessel, üGMS; pushed convoy, SV) and various dimensions (length and width), with different discharge conditions (low, medium and high water) on the River Rhine (see section 3).

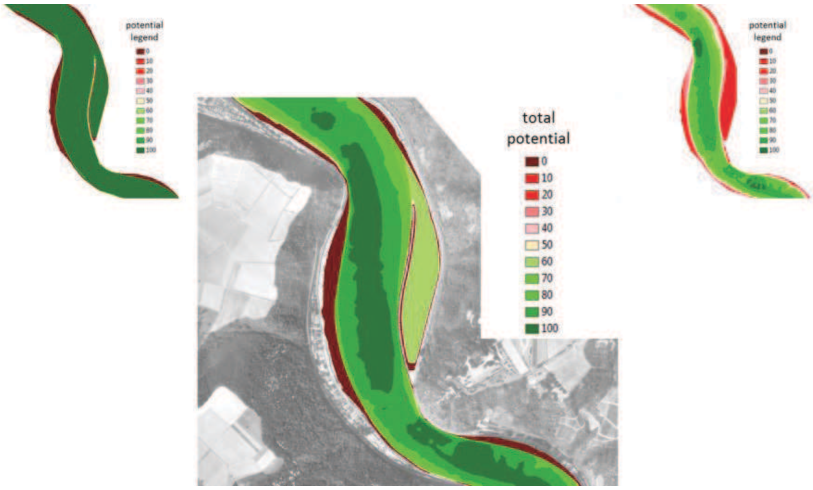

Fig. 6. Example of the development of a total potential based on weighted flow information (flow depth and flow velocities); downstream navigation during high water discharge

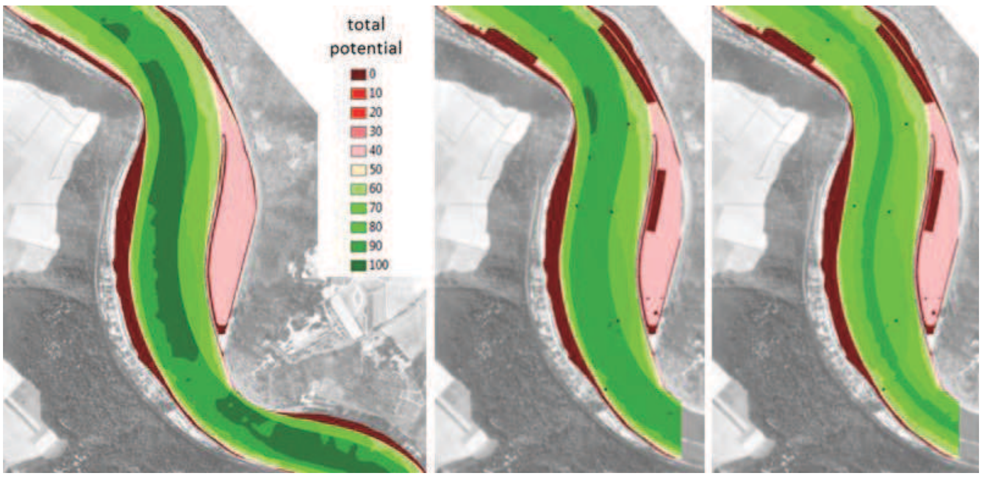

Fig. 7. Example of the development of a total potential; downstream navigation during high water; derived from flow data (flow depth and flow velocities) and Inland ENC information (fairway (left), berth areas, fairway buoys (centre), high water provisions (right))

2.4. *Softwaresystem RiNA*

The preparation, processing and combination of the heterogeneous interdisciplinary input data and the calculation process, development of the potential and analysis of the results are extremely complex and require software engineering support. Based on a globally applied geographic information system ArcGIS the *RiNA* (*River Navigation Assessment*) procedure was developed as an integrated application module so as to enable the use of existing functions. Fig. 8 shows the architectural elements of *RiNA* [1].

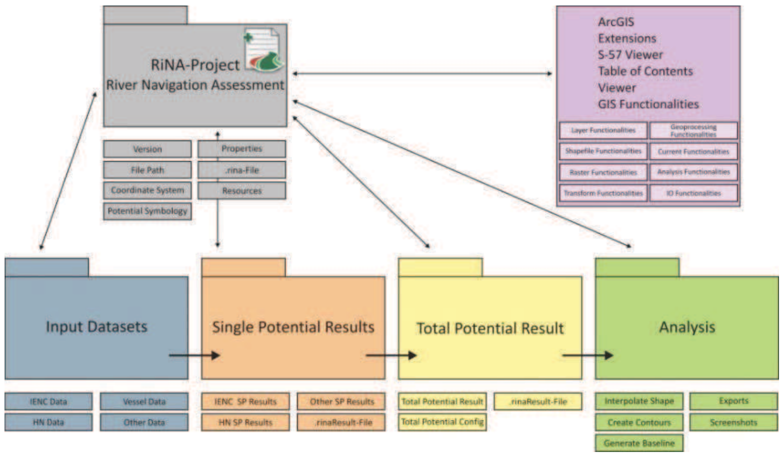

Fig. 8. Architectural elements of *RiNA* (modified according to [1])

3. Case study

The validation of the total potential is based on recorded passages of inland vessels and can be made by visual comparison and statistical analysis of the used ship areas. Fig. 9 shows the mean total potential in the fairway and in comparison also of the recorded vessels downstream at low water (left) and upstream at high water level (right).

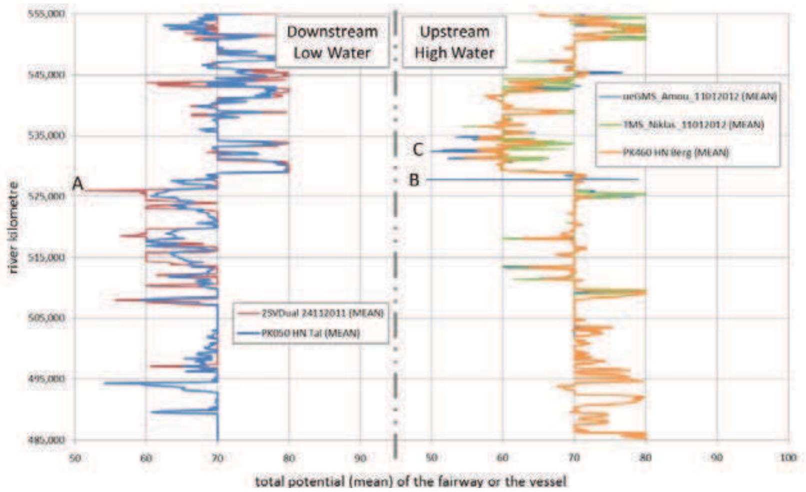

Fig. 9. Comparison of the total potential in the fairway and of recorded passages of inland vessels

Based on the total potential comparative statements about the quality of a passage can be met e.g. by summation of the mean values. Besides, divergences can be analysed to the total potentials of single passages. The markers in the Fig. 9 point significant places downstream and upstream where e.g. the vessels cross lower potential areas in the fairway (Fig. 10) because of low water depths (A) or because of high velocities (C) and where berthing or lay off manoeuvres were conducted (B).

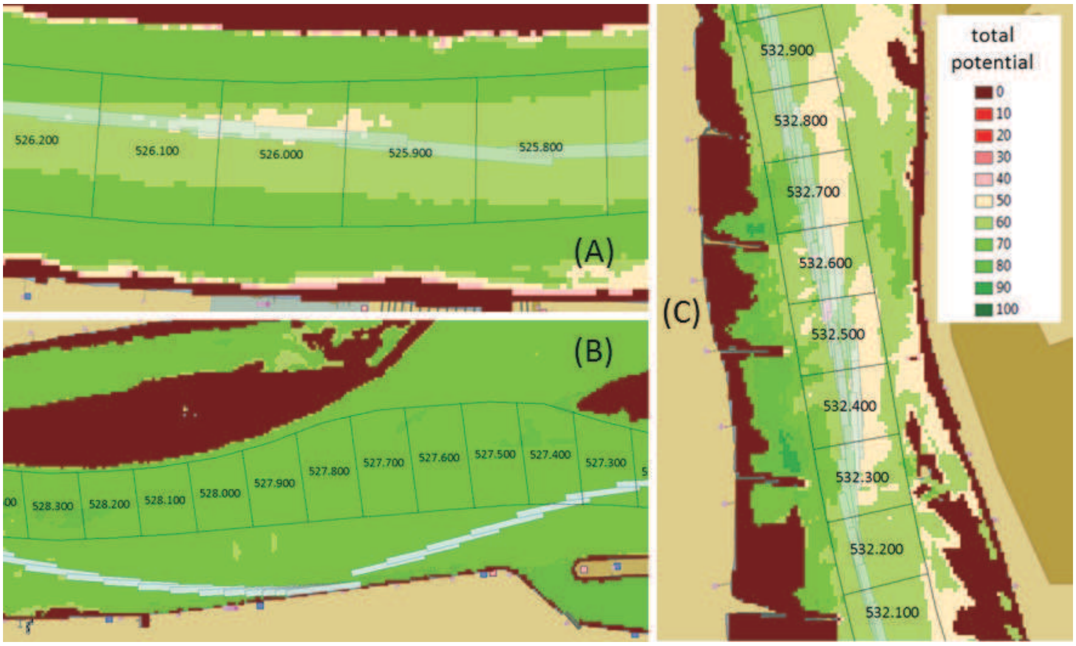

Fig. 10. Comparison of recorded passages downstream at low water level (A) and upstream at high water level (B, C)

In addition, the recorded passages are used to improve the development of the total potentials, while additional single potentials are generated by consideration the Inland ENC objects or by complementary information for example navigation rules. Depending on the objective of the question the weighting factors must be distributed. In a pure analysis and discovering of depth bottlenecks e.g. the single potentials from the velocities have a minor part. However, these must be considered e.g. because an upstream going vessel is more efficient in areas with lower velocities. The total potential can also be used in the Inland ENC with the radar overlay to support the ship master or as a basis to develop an appropriate course.

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